

LONG DURATION EXPOSURE FACILITY (LDEF) ARCHIVE SYSTEM

Brenda K. Wilson

Boeing Aerospace Operations, Inc.
3221 N. Armistead Avenue, Suite B
Hampton, VA 23666-1311

ph 804-766-8976 / fax 804-766-8977 / e-mail b.k.wilson@larc.nasa.gov

SUMMARY

The Long Duration Exposure Facility (LDEF) Archive System is designed to provide spacecraft designers and space environment researchers single point access to all available resources from LDEF. These include data, micrographs, photographs, technical reports, papers, hardware and test specimens, as well as technical expertise. Further, the LDEF Archive System is planned such that it could be the foundation for a NASA Space Environments and Effects (SEE) Archive System, with the addition of other spaceflight, laboratory and theoretical space environments and effects data and associated materials. This paper describes the current status and plans of the LDEF Archive System.

BACKGROUND

The multi-year studies of the retrieved LDEF by hundreds of investigators have resulted in a large, unique and valuable set of resources on the environments in low Earth orbit (LEO) and the effects of these environments on spacecraft and space operations. These diverse resources were generated by many organizations in the federal government, industry and academic institutions. Since the original LDEF Project Plan involved returning its payloads to their principal investigators with no project involvement in data collection and analyses, no central archival plans were made.

NASA is required to archive data from spaceflight experiments in accordance with the requirements of the National Archives. Also, NASA has an agreement with the National Air and Space Museum of the Smithsonian Institution, which gives the National Air and Space Museum the right of first refusal of NASA's spaceflight hardware.¹ NASA has the right to keep spaceflight hardware for as long as it desires, but the National Air and Space Museum must be given the first opportunity after NASA to assume responsibility for the hardware.

Other aerospace databases and data centers relate to the LDEF Archive System. These include the National Space Science Data Center (NSSDC), which has operated for 28 years as an active repository for space and Earth science data from space experiments and ground-based observations.^{2,3} Over the past four years, LDEF special investigation groups and principal investigators have developed focused databases generally oriented toward specific LDEF experiments, areas of special investigations or disciplines. These local databases reside on minicomputers, workstations and personal computers and employ a variety of database management software for data storage and retrieval. In addition, these databases are characterized by custom user interfaces and access mechanisms.

The LDEF activities have brought together a community of space environment and effects researchers and form the basis for a continuing space environments and effects program. While NASA has not maintained a comprehensive SEE program throughout its history, in recent years

the NASA Office of Advanced Concepts and Technology (OACT) and NASA Langley Research Center (LaRC) have placed emphasis upon the development of a SEE Program. Although the program is in its early stages, the following general technical discipline areas have been identified: ionizing radiation; meteoroids and orbital debris; neutral external contamination; plasmas and fields; thermosphere, thermal and solar conditions; electromagnetic effects; materials and processes; and environmental model and database integration.⁴ Technical working groups, similar to the LDEF special investigation groups, have been established in these areas.

Boeing Aerospace Operations, Inc. (BAO) has defined the structure of the LDEF and proposed SEE Archive System for the LDEF Science Office at NASA LaRC, and is in the process of identifying and assembling the detailed contents. NASA LaRC's Information Systems Division (ISD) has provided and interfaced the computing resources in the form of hardware, software and network components required to develop the Online Archive System. ISD and BAO will work to integrate the distributed LDEF data into a centrally accessible archive system. This activity also involves the LDEF principal investigators, special investigation groups and contractor organizations. The four LDEF special investigation groups, focused upon ionizing radiation, meteoroids and debris, materials and systems, were directed by the LDEF FY 1994 plan to support the development of the LDEF Archive by identifying and making available to BAO all archivable information.

ARCHIVE SYSTEM DESCRIPTION

Overview

The LDEF Archive System is comprised of two parts. The first part is the physical contents of the archive, including space flight and ground control hardware, documentation, data, photographs and publications. The second part is the electronic or online system. It is available to users via the Internet, and it takes advantage of public domain software whenever possible.^{5,6} It contains data files, both numerical and graphical image files, micrograph and photograph image files, technical report abstracts and full text files.

The elements of both components of the LDEF Archive System, physical and electronic, are categorized according to the following:

- Directory
- Project / Mission Documentation
- Experiment Documentation
- Hardware
- Data / Analysis
- Photographs
- Publications

The LDEF Archive System elements can also be viewed from the perspective of technical disciplines:

Environments and their effects:

- Ionizing Radiation
- Meteoroids and Debris
- Neutral External Contamination
- Plasmas and Fields
- Thermal and Solar

Environmental effects-related:

- Electromagnetic Effects
- Materials and Processes
- Systems

These technical discipline classifications reflect the areas of LDEF special investigations and the structure of the developing SEE Program. Figure 1 illustrates the elements of the LDEF Archive System.

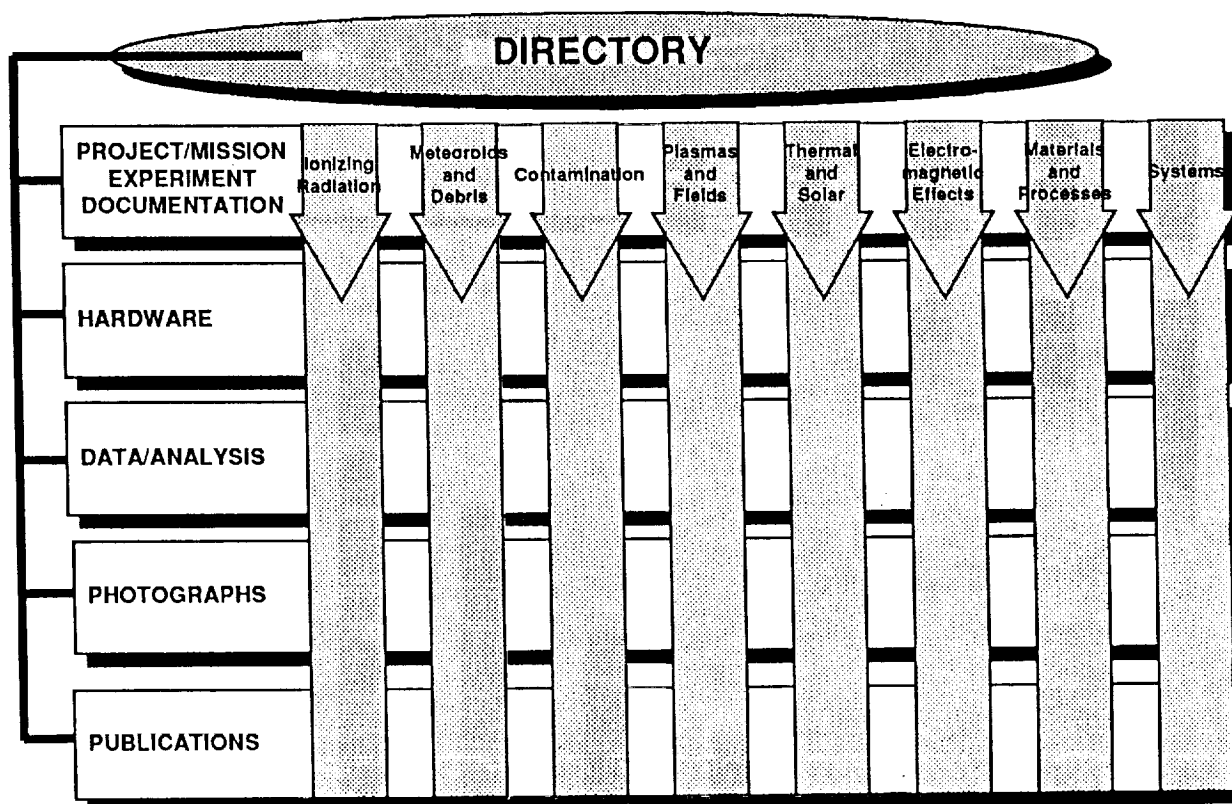


Figure 1. LDEF Archive System.

The LDEF Archive is a distributed system, and both physical and electronic segments are maintained at a host of locations. The LDEF Archive at NASA LaRC has the ultimate responsibility for the total system, and it is the location to which all hardware, data and associated materials should be sent when they are no longer maintained at investigators' facilities. The remainder of this section includes a discussion of the Online Archive System, followed by descriptions of the elements and their incorporation into the final product.

Online Archive System

The Online Archive System will provide the single point of entry to the resources of the LDEF Archive System. This concept is illustrated in Figure 2. A prototype was developed in Autumn 1993 that contained network access to the following data systems: LDEF Meteoroids and Debris Special Investigation Group Database at NASA Johnson Space Center, the Jet Propulsion Laboratory/NASA Ground Test Radiation Data Bank (RADATA) at JPL and the Materials and Processes Technical Information System (MAPTIS) at NASA Marshall Space Flight Center. It also contained access to a small set of digital images of LDEF photographs and accompanying descriptions. This prototype was demonstrated to attendees of the Third LDEF Post Retrieval Symposium in Williamsburg, VA, in November 1993.

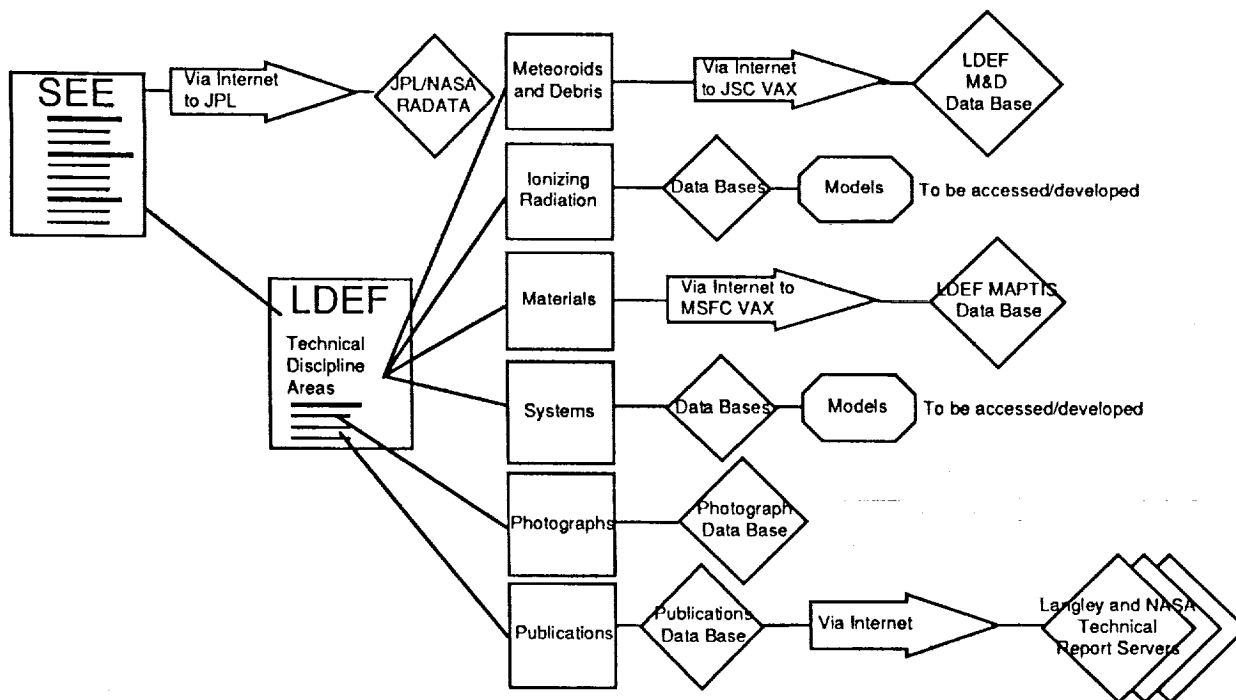


Figure 2. Online LDEF Archive System concept illustration.

The LDEF Archive System has been established on a UNIX workstation at NASA LaRC, and it is accessible via Internet. The LDEF Archive System's capability to reach out to other data systems is achieved through the use of an Internet information service referred to as the World Wide Web (WWW). WWW was initially developed by researchers at the Conseil European pour la Recherche Nucleaire (CERN) to enable information sharing among internationally dispersed teams of researchers. Built on a client / server architecture, it is a global hypermedia information retrieval system.^{7,8} Hypermedia is a form of hypertext. Hypertext is text that may be "expanded" to provide links to other text. Hypermedia extends this concept by allowing links to multimedia information, such as images, audio and animations. The hypermedia language utilized by the WWW is referred to as HyperText Markup Language (HTML), which is based on a document formatting language called the Standard Generalized Markup Language (SGML).

The client and server components of the WWW architecture communicate with each other via HyperText Transmission Protocol (HTTP). The WWW client, often referred to as a browser, makes a request for a document to a WWW server, sometimes referred to as an HTTP server. The LDEF Archive utilizes Mosaic from the National Center for Supercomputing Applications (NCSA) as the WWW client, although other WWW browsers are available.

NCSA Mosaic has been developed by the Software Development Group of the National Center for Supercomputing Applications at the University of Illinois at Urbana-Champaign.^{9,10} NCSA receives support from the University of Illinois, the state of Illinois, the National Science Foundation, other government agencies and industry. Mosaic runs on X-Windows displays, IBM and Macintosh personal computers, and it is public domain software. It is available at no cost when downloaded from NCSA via anonymous file transfer protocol (FTP). A minimal cost is charged when NCSA provides Mosaic on disks for IBM or Macintosh PCs through the mail. Information about Mosaic is available from NCSA at the following:

e-mail: mosaic@nasa.uiuc.edu.

phone: (217) 244-0072

In addition to supporting HTTP, NCSA Mosaic also supports other protocols and Internet resource services such as: the File Transfer Protocol (FTP) for retrieving files, Telnet for connecting to remote machines, and the Wide Area Information Servers (WAIS) and gopher for both searching and retrieving information.¹¹ Mosaic also provides internal and external "viewers" for displaying multimedia information including images and audio.

The LDEF Archive System also uses the LaRC-developed Program for Information Storage and Management (PrISM) data tracking software for managing experiment, photograph and hardware information that resides at the central archive site.

The LDEF Archive System and other systems, programs, projects and organizations that are part of the World Wide Web each begin with a "home page," an HTML page that provides the user with descriptive information and serves as the starting point for finding other information. A home page has a function similar to a book cover and table of contents, although it rapidly provides much more information through hyperlinks to the listed items. One can browse through the WWW by using NCSA Mosaic, in a manner similar to paging through a book. Data are presented on pages that appear on the computer monitor, and with the use of the pointer (mouse) one can browse or turn the pages. One can also go directly to a specific page of interest once the page's filename, or Uniform Resource Locator (URL), is known. Each NASA Center and Headquarters has a home page; the URL for the home page for NASA LaRC is:

<http://www.larc.nasa.gov/larc.html>

Figure 3 shows a portion of the NCSA Mosaic menu and the URL entry option.

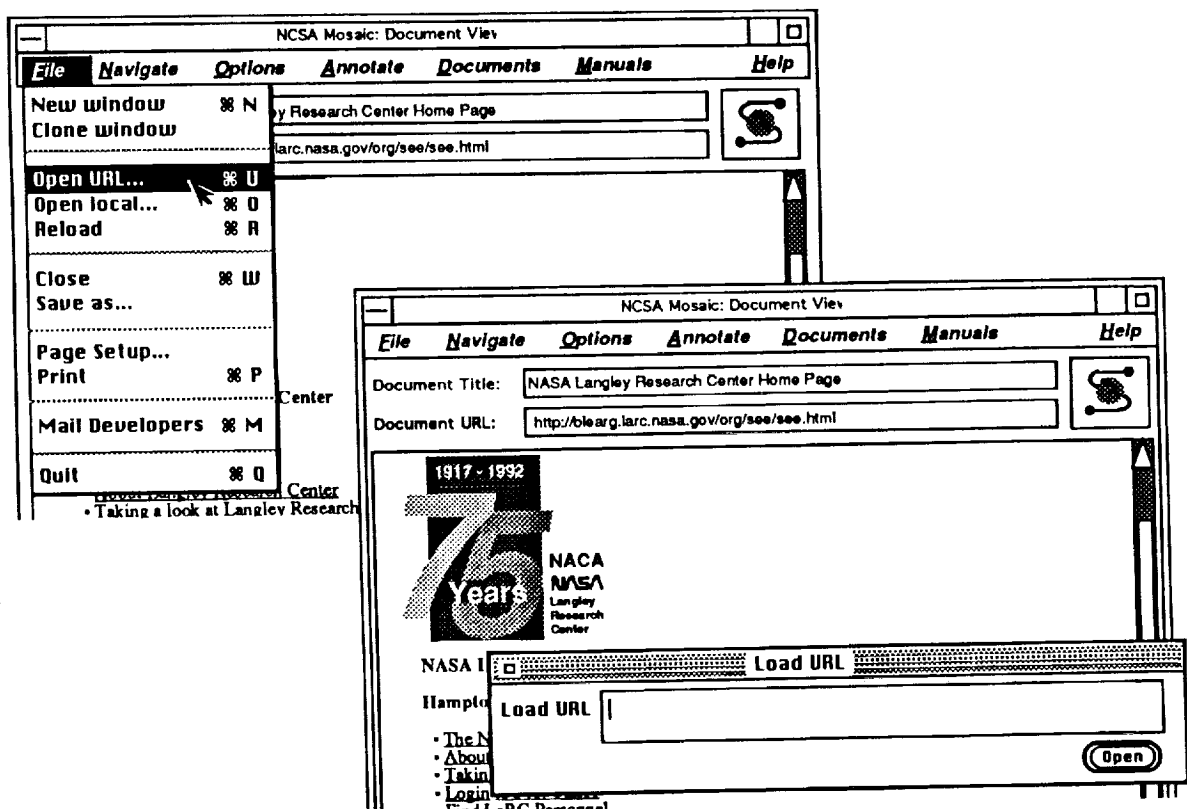


Figure 3. Uniform Resource Locator (URL) entry option.

The entrance to the LDEF Archive System is through a Space Environments and Effects Archive System home page. This is shown in Figure 4. Since the SEE Archive System is intended to access data in addition to that from LDEF, the items listed on the SEE Archive System home page can be modified as the SEE Archive System grows. The SEE Archive System will be listed on the LaRC home page; it is also available through the URL:

<http://blearg.larc.nasa.gov/org/see/see.html>

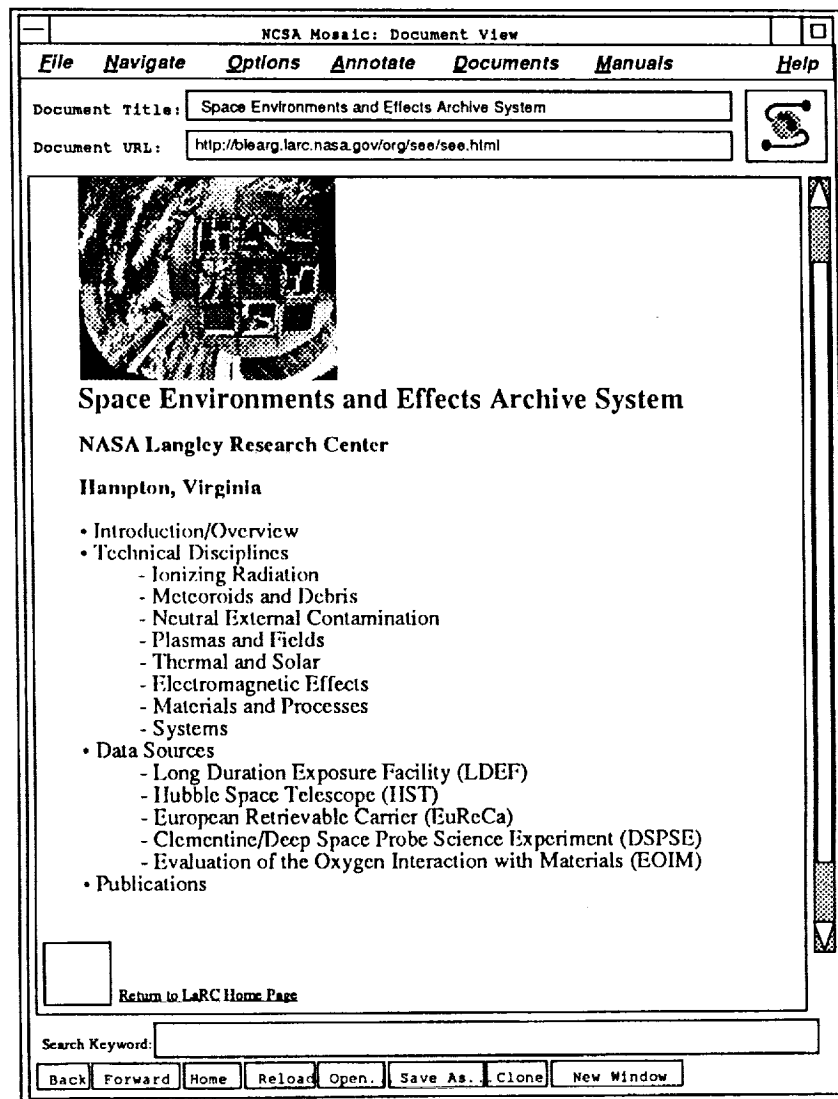


Figure 4. Space Environments and Effects Archive System home page for LDEF access.

Selection of the *Overview* hypertext will lead the user to a page of descriptive information. The *Technical Disciplines* hypertext will lead the user through the system according to the particular area of interest. The *Data Sources* hypertext will lead the user through the system according to a particular space mission or experiment of interest. A *technical discipline-oriented* and a *data source-oriented* path are illustrated in Figure 5. Both paths will lead the user to the same LDEF data area.

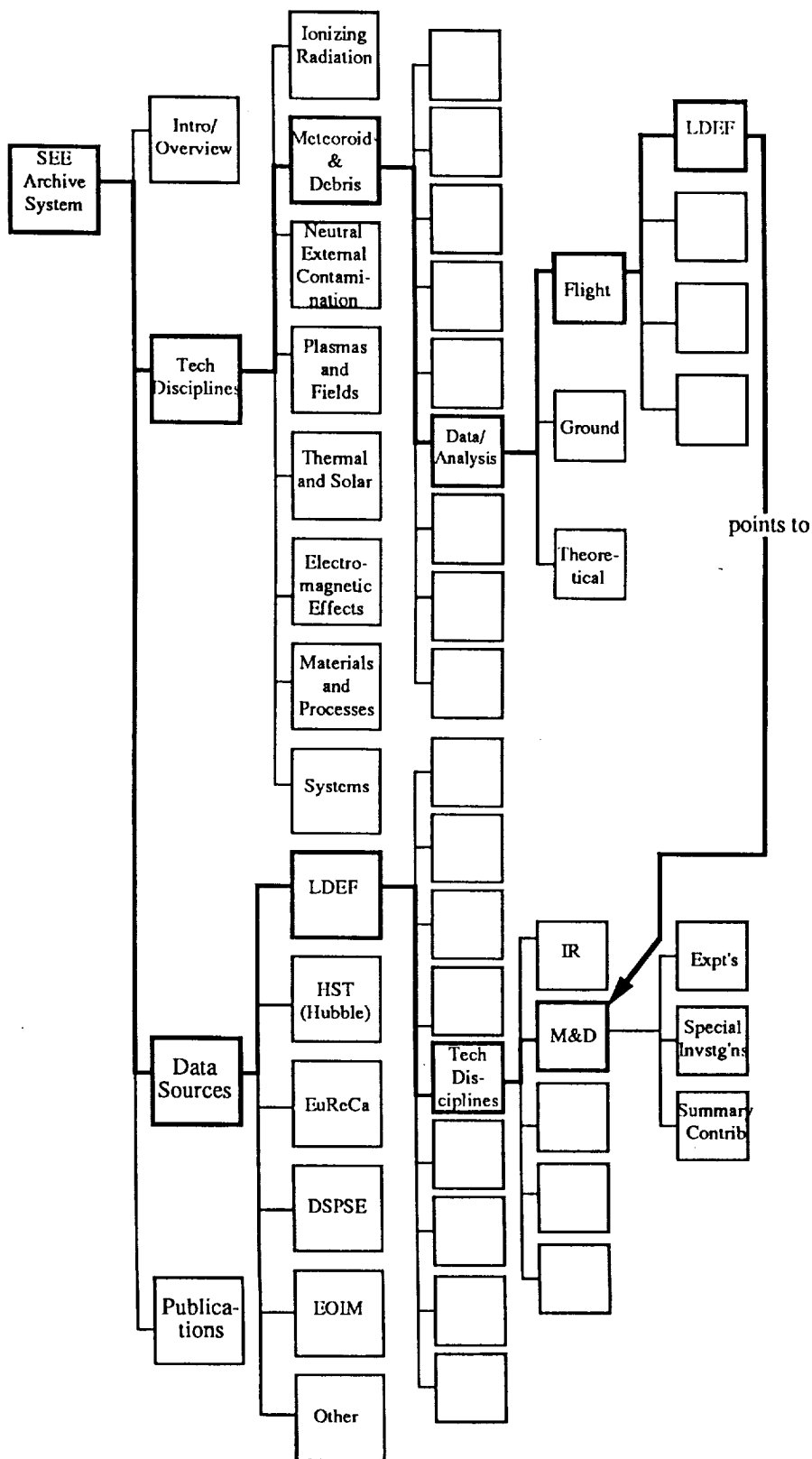


Figure 5. Technical discipline vs. data source oriented pathways through the Archive System.

The LDEF Archive System home page is illustrated in Figure 6. One can reach this page through the LaRC home page, the SEE Archive System home page, or directly through the URL:

<http://blearg.larc.nasa.gov/org/see/ldef.html>

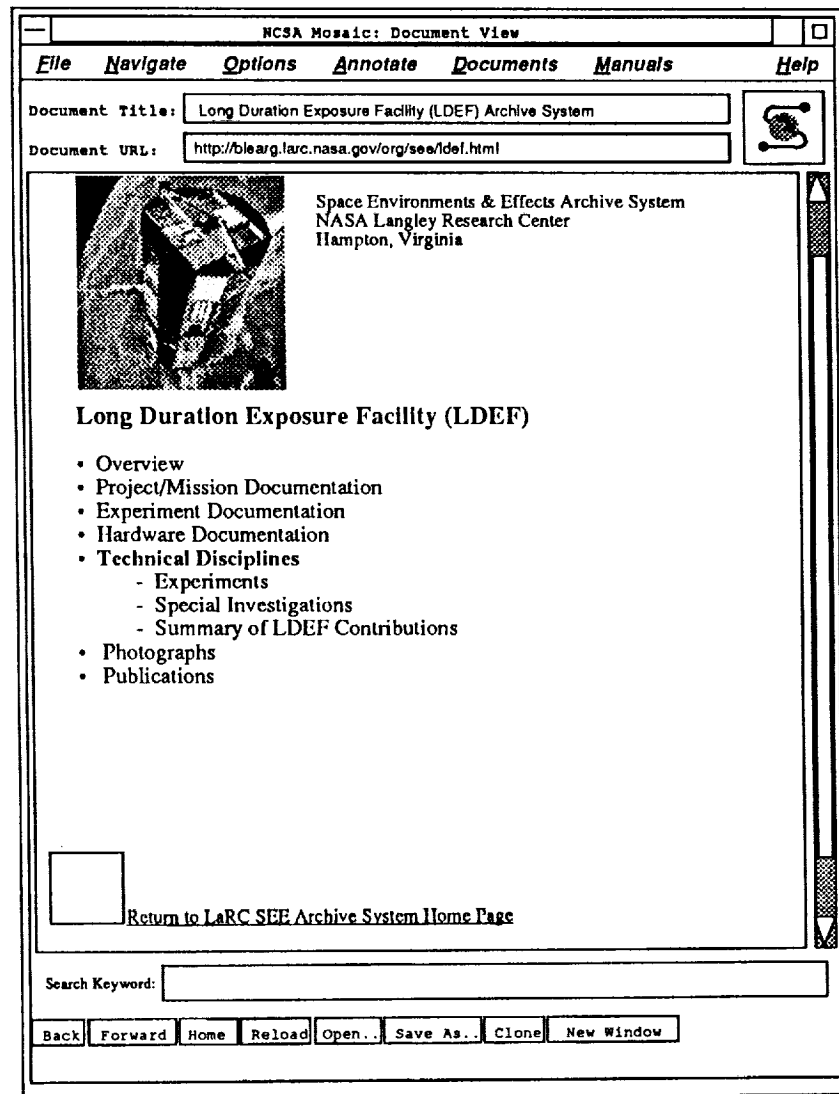


Figure 6. LDEF Archive System home page.

Portions of the LDEF Archive System can be searched through the use of the NCSA Mosaic interface to WAIS, which enables full-text searching of varied databases. WAIS employs a keyword search program from a client machine, and it searches databases that can be located on different server machines.

Physical and Online Aspects of Archive System Elements

Project / Mission Documentation

The project / mission documentation archive element contains the technical plans, design review documents, safety analyses, stress corrosion, electromagnetic interaction and structural failures testing and analyses records. It includes documentation on the Announcement of Opportunity process to acquire experiments and the memoranda between NASA and other organizations. It also will include the data recorded during flight operations at Johnson and Kennedy Space Centers. Currently the documentation is in the LDEF Archive and in the files of LDEF Project staff. The LDEF Science Office is responsible for organizing and preparing these documents and their associated descriptive information for archival. This is planned to be done in conjunction with Lockheed Engineering and Sciences Company, which has a task to author a NASA publication on the LDEF history. The documentation is organized chronologically:

- General
- Concept Development and Design Philosophy
- Facility Design and Development
- Acquisition and Project Tasks in Experiment Development
- Experiment Development Organization Tasks
- Experiment / LDEF Integration Engineering
- LDEF / Space Transportation System (STS) Integration Engineering
- Integration Operations
- Launch
- Orbit
- Retrieval
- Post-Retrieval Deintegration Operations

The Online Archive System will contain at a minimum an identification of the project / mission documents in the archive. Any LaRC-published reports on this area will be included when completed.

Experiment Documentation

The experiment documentation includes experiment number, title, location on LDEF, principal investigators, description, approach, objective, payload materials usage list and drawing list. The Archive will contain a complete set of the 1,461 LDEF as-flown experiment drawings and the 358 LDEF structure drawings. The drawings with LaRC numbers are also archived by LaRC on microfiche.

Hardware

This archive contains flight and ground specimens associated with the LDEF experiments and facility. Hardware is located at the LDEF Archive adjacent to NASA LaRC, NASA Johnson Space Center (JSC), Marshall Space Flight Center (MSFC), Kennedy Space Center (KSC) and principal investigators' laboratories. Principal investigators may retain their hardware as long as they wish. When they no longer wish to retain it, they will return the hardware to the LDEF Archive in Hampton, VA.

Data / Analysis

The results of LDEF investigations have been recorded in databases, lab journals, files, reports and publications. Many LDEF researchers have developed focused databases to review, maintain and access the LDEF resources in specific disciplines. LDEF data have also been used in the development of space environment and environmental effects models.

The data / analysis archive is organized according to technical disciplines. Two special investigation groups have created remote databases that are accessible directly from the LDEF Archive System by using the capabilities of the Mosaic browser and the WWW server. These are the Meteoroids and Debris Special Investigation Group Database at NASA JSC,¹² and the Materials Special Investigation Group Database at NASA MSFC.¹³ The M&D database at JSC is located under the M&D Special Investigations page of the LDEF Archive System; its access from the LDEF Archive System via the Mosaic interface to Telnet is illustrated in Figure 7.

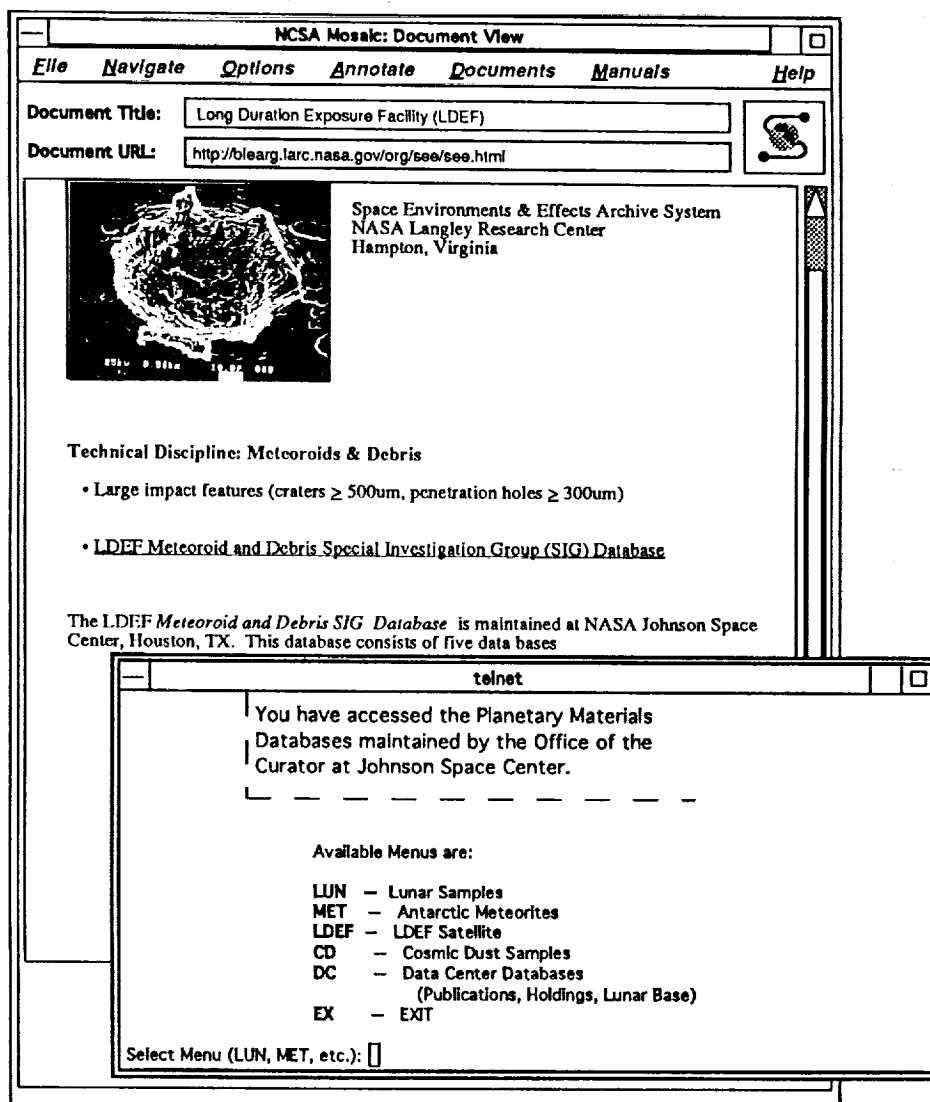


Figure 7. Access of the LDEF Meteoroids and Debris Special Investigation Group Data Base.

While the M&D database can be accessed without a password, the Materials SIG database requires that the user obtain a password from the Materials and Processes Technical Information System (MAPTIS) at MSFC prior to accessing. Also as part of Materials and Systems SIG activities, Boeing Defense and Space Group has created a set of specialized databases for use on personal computers that address optical materials, thermal control coatings, silverized Teflon, treated aluminum, and LDEF environments.¹⁴ In addition to being available on disk for use with Filemaker® Pro [Claris Corp.] software, these databases are planned to be accessible through the Online Archive System.

Principal investigators have used commercial and public domain software to create databases. PI databases using commercial software include Aerospace Corporation's M0003 Deintegration Database available for use with Fourth Dimension™ [ACIUS, Inc.] and Paradox® [Borland International, Inc.] software. The Technical University of Munich has developed hypermedia databases using the public domain Mosaic software from NCSA. They include data, micrographs, photographs, publications and other items relative to LDEF experiments AO187-1, AO187-2, AO201 and S1003. These databases will be accessible via the LDEF Archive System.

In general, the Online Archive System will identify what databases are available, in what form, and how they are available. Through the use of NCSA Mosaic, the databases available via the Internet will be accessible from the Archive. Some of the databases that are available for use with commercial software are also planned to be network-accessible.

Photographs / Videos

More than 20,000 photographs of LDEF, LDEF experiments, samples and research efforts are currently in the collections of LaRC, KSC, JSC, MSFC and principal investigators. Individual photographic surveys were taken by NASA during the pre-launch period, STS-41C (originally STS-13) deployment flight, STS-32 retrieval flight, Edwards Air Force Base operations, and KSC operations, including those at the Demating, Orbital Processing, Operations and Checkout Facilities and the Spacecraft Assembly and Encapsulation Facility II (SAEF-II). The SAEF-II photographic records are extensive and cover the initial visual inspection period, deintegration of experiments, facility and systems. Each experiment tray was the subject of a detailed photo survey immediately following deintegration. Individual principal investigators also have extensive photographic collections, and efforts are being made to include copies of these collections in the LDEF Archive.

The Online Archive System will contain at a minimum three images for each LDEF tray location and experiment: preflight, on-orbit and post-flight. Currently only the on-orbit photo images have been entered. Graphical Interchange Format (GIF) and Tagged Image File Format (TIFF) files are part of the system. No standard digital image format exists in practice within NASA or within the broad archive community.

Lockheed Engineering and Science Company has a task from NASA LaRC to catalog LDEF photographs and videos, and to produce a document of LDEF photographs for NASA publication. The parallel activities are being coordinated in order to produce complementary products.

Publications

The LDEF Archive will contain a copy of all LDEF-related publications available. These include publications in professional journals, NASA publications, other government publications, books, newspapers and other sources.

The Online Archive System will utilize the online document retrieval services being developed by NASA LaRC's Information Systems Division, including the Langley Technical Report Server (LTRS) and the NASA Technical Report Server (NTRS).¹⁵ It will also access other technical report servers as they relate to LDEF and as they become available. The goal over the long term is to be able to provide access to the extensive publications databases and retrieval services that currently are available through a combination of government and commercial publications databases.

INTERACTION WITH USERS

The prototype of the Online LDEF Archive System was developed in Autumn 1993 and was available for review at the Third LDEF Post Retrieval Symposium in November 1993. Since that time, BAO has worked with system users who have expressed comments. It is planned that a more comprehensive draft will be available in mid-1994, and a form has been incorporated in the system to enable users to reply via e-mail regarding the system.

In the developing Space Environments and Effects Program, the technical working groups comprise the greatest technical expertise related to their discipline, and it will be these groups that are responsible for the development of space environment models, environmental effects modeling, design criteria, guides and knowledge base systems. The Space Environments and Effects Archive will be the resource upon which these groups can draw in order to build these products.

INTERACTION WITH OTHER DATA SYSTEMS AND ARCHIVES

Lessons have been learned from other archives and data systems that have similar objectives to the LDEF Archive System but that do not necessarily contain space environments and effects data. BAO participates in Internet discussion groups on museums and archives that have a total of several thousand members interested in the development of systems to catalog, access and archive diverse resources for users with varied needs and computer capabilities. It is clear that while some standards exist for cataloguing items, the technologies for data storage evolve rapidly and standards do not cover the growing range of data storage and access options. BAO has also consulted with a broad set of organizations including the NSSDC and some of its affiliated data systems, such as the Planetary Data System; the Library of Congress; the Smithsonian Institution; and organizations at LaRC active in data storage and retrieval, including the Earth Observing System Data and Information System (EOSDIS) Distributed Active Archive Center (DAAC).

Key to the development of a useful and efficient system is the definition of requirements prior to establishing formats for data storage, media and access. Also, any system must be flexible enough to adapt to changes in data storage technologies. Computer technology can advance dramatically in one year, as in the case of NCSA Mosaic.

In addition to the LDEF-related computer network-accessible systems discussed earlier, more systems are coming online that relate to the LDEF Archive System and space environments and effects. A number of NASA Centers have programs devoted to space environments and effects, and Department of Defense laboratories similarly have areas of focused SEE-related research. As appropriate, links to these systems are planned as part of the proposed SEE Archive System.

CONCLUDING REMARKS

The purpose of LDEF Archive System is to maintain LDEF data, analysis, hardware, photographs, documentation and publications as a long term resource, and to provide easy access to these distributed elements. BAO is developing the LDEF Archive System as the single point of entry into the distributed LDEF resources and areas of technical expertise maintained at different locations. When it develops into the SEE Archive System, it will be the gateway for the growing quantity of space environments and effects data distributed throughout the aerospace research community.

It is hoped that this system will lead to more data archival and technology transfer planning at the outset of space experiment planning. As more space environment and effects data are generated, it becomes increasingly important that the raw data be available for review, application and comparison. NASA-funded research results are typically made available through published papers; with the advances in personal computer capabilities and network technologies, not only the papers but the data files can be downloaded for use at the researcher's desk.

A SEE Archive System is an essential basis for the development and subsequent utilization of space environment and effects models, design criteria, guides and knowledge base systems. A SEE Archive System will be the resource in which space researchers and spacecraft designers can store and access data, and it will be the means through which data, models, design tools and hardware can be disseminated. Key to the archive's success will be the coordination with principal investigators prior to missions on the definition of requirements for data archival and access after flight. The proposed SEE Archive System was developed based on the anticipation that the structure of the SEE Program would be as illustrated in Figure 8.

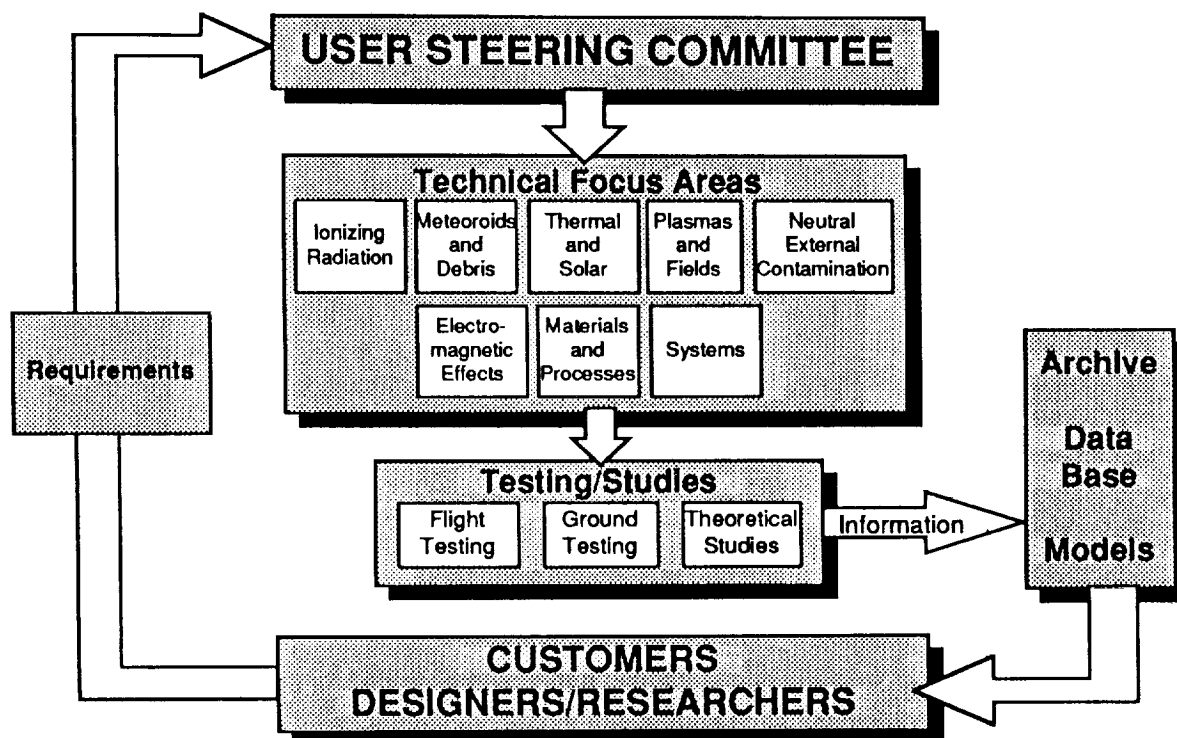


Figure 8. Space Environments and Effects Program and Archive System concept.

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